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California Institute of Technology
Division of Engineering and Applied Science

CHAOS and TURBULENCE

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Professor P.G. Saffman, Professor of Applied Mathematics

This report describes the theoretical work carried out by P.G. Saffman and associates.

Personnel

The following faculty, postdocs, visitors and students carried out theoretical research on the project or provided consulting.

Faculty:
P.G. Saffman, Professor of Applied Mathematics
D.I. Meiron, Assistant Professor of Applied Mathematics

Post-docs:
Dr. D. Barkley

Visitors:
Dr. J. Jimenez
Professor R. MacKay
Professor F. Milinazzo
Professor D. Moore
Professor S. Tanveer

Graduate Students awarded Ph.D's:
J. Kamm (1987)
M. Landman (1987)
J. Pugh (1987)
V. Rom (1987)
M. Rotenberry (1989)
I. Soibelman (1989)

Publications supported:

P.G. Saffman & D.I. Meiron 1986 Difficulties with three-dimensional weak solutions for inviscid incompressible flows. Phys. Fluids 29, pp2373-2375.

M.J. Landman & P.G. Saffman 1987 On the 3-dimensional instability of vortices in a viscous fluid. Phys. Fluids 30, pp2339-2342.

J.D. Pugh & P.G. Saffman 1988 Two-dimensional superharmonic stability of finite amplitude waves in plane Poiseuille flow. J. Fluid Mech. 194, pp295-307.

P.G. Saffman 1988 The stability of vortex arrays to two and three dimensional disturbances. Fluid Dynamics Res. 3 pp13-21.

R.S. MacKay 1987 Instability of vortex streets. Dyn. Stab. Sys. 2 pp55-71.

M.J. Landman 1987 Solutions of the Ginzburg-Landau equation of interest in shear flow applications. Stud. App. Math. 76, pp187-237.

M.J. Rotenberry & P.G. Saffman 1990 Effect of compliant boundaries on weakly nonlinear shear waves in channel flow. SIAM J. Applied Mathematics (to appear).

D. Barkley & A. Cumming 1989 Thermodynamics of the quasi-periodic set at the transition to chaos: experimental results. Phys. Rev. Lett. (sub judice).

D. Barkley & A. Cumming 1989 Experimental study of the multifractal structure of the quasiperiodic set.

Proc. NATO Conf. Quantitative measures of dynamical complexity in nonlinear systems. Bryn Mawr College June 21-25 1989.

D. Barkley 1989 Theory and predictions for finite amplitude waves in Plane Poiseuille Flow. Bull. Am. Phys. Soc. (to appear).

Ph.D. degrees awarded:

Michael J. Landman (1987) New solutions of an amplitude equation describing transition in a laminar shear flow.

James R. Kamm (1987) Shape and stability of two-dimensional uniform vortex regions.

Jeffrey Pugh (1987) Finite amplitude waves in plane Poiseuille flow.

Vered Rom (1987) I. An analytical study of transport, mixing and chaos in an unsteady vortical flow. II. Transport in two-dimensional maps.

James M. Rotenberry (1989) Effect of compliant boundaries on weakly nonlinear shear waves.

Israel Soibelman (1989) A study of finite amplitude bifurcations plane Poiseuille flow.

Summary of research

The main thrust was the attempt to find low order systems possessing chaotic behavior which could successfully model turbulent flow. The reason for searching for low order systems is the evidence (not completely supported or convincing but strongly suggestive) that 'chaos' disappears in systems with a large number of degrees of freedom. Recent work on symplectic integration of Hamiltonian systems indicates that for Hamiltonian systems chaos may be no more than numerical error growing exponentially, and is absent when the numerical scheme conserves the Poincare invariants and the symplectic structure.

A great deal was learned about vortical solutions of the Navier-Stokes equations and new solutions of a weakly nonlinear approximation were found, which suggest the existence of Navier-Stokes solutions which will describe a vortical description of the laminar turbulent interface. This work is described in the published papers and Ph.D. theses. But the primary objective was not attained, due to the difficulty in finding suitable flow modules whose interaction could be adequately described by a low order system.

Vered Rom's thesis constituted an interesting application of dynamical system theory to a problem of kinematic mixing, and showed that the use of these ideas could reduce the dimension of the system in order to make computations feasible, and predict the qualitative development of the distribution of mixed tracer in an unsteady flow.

Recent efforts were directed towards understanding the Hamiltonian structure of vortical flows, developing methods of symplectic integration, extending and using the methods of dynamical systems to explain and predict the geometry of newly discovered vortical solutions of the Navier-Stokes equations, and modelling the laminar-turbulent transition in Poiseuille and Couette flow, i.e. the structure of turbulent slugs, puffs and slugs. Studies of a novel method of searching for bifurcation from infinity were started in order to explain the instability of linearly stable flows such as plane Couette flow and pipe flow and stable boundary layers. It is planned to continue this work as far as possible with the limited support now available form other sources.